INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

Aquitard Characterization

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INTRODUCTION

An **aquitard**, for the purpose of this technical guidance document, is a geological unit of low permeability that can store ground water and contamination and also transmit them slowly from one aquifer to another.

When investigating contamination in soil and ground water, contaminant behavior through porous media is predicted using many of the following assumptions:

1) Subsurface materials are relatively flat lying and are continuous across the study area;
2) Groundwater flows horizontally and in predictable directions;
3) Perched groundwater is not connected to the water table;
4) Groundwater flows toward the nearest stream; and
5) Contamination will flow horizontally with the ground water.

When investigating geological settings that include aquitards, these common assumptions should be re-examined.

Conceptual Framework

Most subsurface investigations focus on aquifers and ground water availability. However, when low permeability layers are present locally or regionally, they can greatly affect the ground water flow path. The ground water flow path, in turn, greatly affects the contaminant fate and transport. Aquitards are often mischaracterized as homogeneous and massive, and interpretations about how these units affect ground water flow are often incorrect. Some key concepts to keep in mind when developing a conceptual site model (CSM) that involves an aquitard:

- Ground water is not static and flows through aquitards,
- Aquitards can have sufficient areal extent, thickness, and geometry to impede or deflect ground water flow from or into aquifers,
- Aquitards can determine flow paths and serve as storage units for both water and contaminants,
- Ground water often spends more time in aquitards than in aquifers, and

- Hydraulic properties can cause very long response times to water levels and changes in ground water flow.

These same key concepts will influence contaminant flow through an aquitard.

If a clay unit of sufficient thickness is encountered in a boring, the investigator often assumes contamination will not migrate any deeper. However, if these clays are fractured or are not continuous, it is possible that contamination may migrate deeper. In addition, aquitards can also store water and contamination and release them into surrounding materials slowly.

When dealing with aquitards, there are important issues involved in developing a CSM:

- **Aquitard Surface Flow**: Contaminants can flow preferentially along the surface of an aquitard rather than horizontally and with ground water flow.
- **Aquitards and Natural Preferential Pathways**: Looking at the material without evaluating the macroscopic features may cause an over estimation of the aquitard’s resistance to flow. Common vertical structures can be fractures, macropores, or plant roots.
- **Extent of an Aquitard**: In order to be an effective barrier to vertical flow, an aquitard has to have sufficient known thickness and extent. Evaluation of both thickness and extent are needed to determine if an aquitard is an effective barrier to contaminant migration.
- **Contaminant Migration Through an Aquitard**: The presence of an aquitard does not always indicate a barrier to vertical migration of contaminants. Ground water flows vertically through aquitards rather than horizontally, therefore down-gradient wells need to be located differently than those monitoring aquifers.
- **Shallow Aquitards and Manmade Preferential Pathways**: Shallow low permeability units are typically cut or breached by either natural or anthropogenic (man-made) actions. Low permeability units less than 20 feet deep cannot be considered effective barriers to contaminant migration due to potential human alterations.
- **Aquitards as Sources of Contamination**: Over time, contaminants in contact with an aquitard can become entrained in the pore spaces of the material. The primary mechanism of contaminant transport becomes diffusion into aquifers rather than advective flow.

INVESTIGATIVE CONSIDERATIONS

Aquitard Surface Flow

To understand how aquitards affect ground water flow and contaminant transport, an investigation of the surface of the aquitard is needed.

A common misconception when evaluating the subsurface environment is that all sediments are flat lying and extend laterally in all directions. This is not the case, particularly in the case of glacially deposited aquitards.

Localized aquitards are not true barriers to ground water flow. There are instances where aquitards can deflect or temporarily hold ground water. These smaller units can affect local ground water flow and contaminant transport.

Aquitards and Natural Preferential Pathways

Once the lateral extent of the aquitard is known, an evaluation of it as an effective barrier to contaminant migration is needed. Both thickness and areal extent are factors to consider when evaluating an aquitard. In addition to these factors, an evaluation of both natural and man-made preferential pathways is needed. A copy of the Geological Services *Investigation of Manmade Preferential Pathways* can be found at:

http://www.in.gov/idem/files/remediation_tech_guidance_investigation_mpp.pdf.

This document provides information needed to deal with the common preferential pathways encountered when investigating aquitards.

<u>Bedding Planes</u>

Bedding planes are found in both unconsolidated materials and bedrock. However, these features have different characteristics in each material. In unconsolidated materials, a bedding plane is identified as a change in the characteristics of the material (i.e. change in grain size). In unconsolidated materials bedding plains can deflect, retard, or increase either volume or speed of transport of contaminants. Bedding thickness and composition are important to know when investigating the effectiveness of an aquitard. For example, millimeter thick silt beds within a generally dense, low permeability unit can be the primary contaminant transport mechanism. The more homogeneous the clay or low permeability material the more effective the aquitard is at retarding flow. However for an aquitard to be effective it needs not only sufficient thickness, but it also needs to be laterally extensive.

Most assessments of aquitards assume the material is homogeneous; therefore natural preferential pathways in aquitards are overlooked. Small discrete elements like fractures, macropores, plant roots, and erosional or depositional windows can dominate flow across aquitards. The flow through the material of an aquitard may be so low that a single feature or fracture open to the surrounding aquifer(s) can provide more flow than the aquitard material. These features (natural preferential pathways) will also allow contaminants to migrate vertically (much like contaminant transport in fractured bedrock).

Most investigators do not want to breach the aquitard; therefore the thickness of an aquitard is often unknown. Most clay layers characterized as aquitards are usually penetrated by only a few feet. However, without confirming the thickness of the clay layer, evaluation of the unit as a barrier to vertical migration of contamination is not possible. Modern drilling methods can maintain the integrity of the clay unit while providing the information needed.

Vertical Fractures, Macropores, and Plant Roots:

These features can be found in both unconsolidated sediments and bedrock. In both cases they will have the same effect on contaminant migration. Vertical fractures will allow contamination to move vertically. In addition, in finer grained sediments (like aquitards) and in bedrock vertical fractures can be the primary mechanism of contaminant transport. In the past efforts were made to test the material to determine how well groundwater will flow and ignore the macroscopic structures present. To evaluate fractures a good knowledge of regional structure is needed. Given time most materials will develop fractures. However, it is the interconnection of the fractures that will dictate how water will flow. Fractured clays and plant roots are subsets of vertical fractures and macropores.

- **Fractured Clays**

  Identification of fractured clays is important for two reasons:

  - Fractured clays allow contaminated ground water to migrate vertically; and
  - Fractured clays allow vapors to migrate up-ward

  For an aquitard to be effective the degree of fracturing should be low, otherwise the aquitard would not be considered a barrier to vertical migration of contaminants. The presence of fractured clays and glacial till in Indiana is well documented. See: http://igs.indiana.edu/MarionCounty/PoroAndPerme.cfm for additional information. While this example is from Marion County, the concepts presented will apply to glacial till clays in other parts of Indiana.

- **Macropores**
  Macropores are void spaces in a material that are larger than the spaces between the grains of the material. Most materials testing methods will not identify these features. Most macropores are identified in the field. A detailed field evaluation of the borings is needed to identify macropores. If these observations are not made in the field, valuable information may be lost. Pump tests can also identify the presence of macropores.

- **Plant Roots**

  In instances where an aquitard is shallow, plant roots can breach the aquitard (usually the plant roots are seeking the water table) and allow contamination to migrate deeper into the subsurface. If the site being investigated has a shallow clay layer and well developed vegetation, chances are the roots of the larger plants have breached the aquitard. In addition if part of the aquitard is made up of a paleosol, there could be relic plant root and animal casts that could create preferential pathways.

Thickness of an Aquitard

In order to be an effective barrier to vertical flow, an aquitard has to have sufficient thickness. When clay layers are encountered beneath a water bearing zone, investigators will usually stop drilling. The reason usually given is that they do not want to breach the confining unit (aquitard). If the aquitard is not tested, information showing that the aquitard is or is not protecting a lower water bearing zone will never be collected. Fundamental to determining the "protectiveness" of an aquitard is determining its thickness. For an aquitard to inhibit downward migration of contamination the aquitard needs to be sufficiently thick. .

In addition to knowing the thickness of the aquitard, the geometry of the aquitard needs to be determined. In most cases processes that deposited the aquitard material did not leave behind continuous units. Aquitards can be:

- Truncated or "pinch-out" into an aquifer,
- Discontinuous,
- Incised (eroded),
- Layered with thin permeable zones,
- Contain discontinuous layers of higher conductive zones, or
- Truncated by or in contact with bedrock aquifers.

Ground water and Contaminant Flow Through an Aquitard

Flow through an aquitard is not the same as flow in an aquifer. In general, ground water flows vertically through aquitards and horizontally in aquifers. The flow across the aquifer/aquitard or the aquitard/aquifer contact is refracted. Another difference is the conductivity. Hydraulic conductivity can be orders of magnitude less in an aquitard than an aquifer while the specific storages may be similar.

Contamination will also migrate vertically through an aquitard more quickly than it migrates horizontally. The slow speed of transit could also store the contaminants in the pore spaces of the material (act as a source of contamination). Flow properties for both ground water and contaminants of concern (COCs) need to be known before determining where to optimally place monitoring wells.

Shallow Aquitards and Preferential Pathways (manmade and natural)

When a shallow aquitard is present there are additional elements that need to be included in an investigation. Utility excavations, production wells and building foundations/footers (manmade preferential pathways) could breach a shallow aquitard and allow contamination to migrate into underlying water bearing zones. If a shallow aquitard is suspected, a preferential pathway investigation should be included when developing a CSM.

A Technical Guidance Document has been developed to guide investigations involving manmade preferential pathways. For guidance on preferential pathways, refer to the technical guidance document "Investigation of Manmade Preferential Pathways for Contaminant Transport' at: http://www.in.gov/idem/files/remediation_tech_guidance_investigation_mpp.pdf

Aquitards as Sources of Contamination

If contamination is in contact with a low permeability layer for a sufficient length of time, the contaminant will penetrate and fill the pore spaces of the unit. Once a contaminant replaces water in the pores, it will continue to slowly transmit contamination into the surrounding geologic materials. Thus, as a plume travels down-gradient, the source of contamination changes from vadose zone leaching to saturated zone diffusion. Refer to Bradbury, et al. (2006) and Cherry, et al (2006) for a detailed discussion of the hydraulics controlling this process.

To determine if an aquitard is a continuing source of contamination, ground water samples should be collected from the zone immediately above and from within the aquitard. Should ground water contamination be confirmed, soil samples from the aquitard should be collected to determine the remaining contaminant mass.

Once it is confirmed that the aquitard may diffuse contaminants into the surrounding materials, the natural and manmade preferential pathways should be evaluated to determine if contamination could breach the aquitard. If an evaluation of the preferential pathways reveals there is a potential for contamination to breach the aquitard, the thickness of the aquitard will need to be determined. The thickness needs to be known to determine if the aquitard is sufficient to compensate for the identified preferential pathways. If all of these tests and evaluations show there is potential for a breach, the next deepest water bearing unit should be investigated.

INVESTIGATIVE STRATEGIES

Investigation of an aquitard is similar to the initial investigation steps taken when investigating karst, shallow bedrock or fractured bedrock. Once the contaminant is found in an area where an aquitard is affecting its distribution, an investigation of the interface between the porous materials and the suspected aquitard is needed, to determine if the interface itself could be affecting contaminant transport. There are several tests to conduct to determine if the surface needs further study:

<u>Mapping the surface of the aquitard</u>.

Mapping the surface of an aquitard is a simple way of determining how water is draining through, and in the case of an aquitard along, the subsurface materials beneath the site. Geophysics can provide data both to locate potential "problem areas" where boring programs should be focused, and allow accurate interpretation of data between borings. Some of these methods can also provide information regarding the thickness of the aquitard. Examples of land-based geophysical methods include:

- **Electromagnetics (EM) and electric imaging (EI):** These methods are used to detect variations in subsurface electrical properties related to anomalously thick or wet soils (will produce an electrical conductivity high response), or voids in the electrically conductive clay soil (will produce an electrical conductivity low response).

- **Spontaneous potential (SP):** This method is used to detect naturally occurring minute electrical currents/potentials commonly associated with concentrated infiltration or subsurface movement of water.

- **Microgravity:** This method is used to map minute variations in gravity that may be due to soil voids or bedrock fractures where "missing" subsurface mass results in measurably lower gravity.

- **Seismic refraction, reflection, and surface wave analysis:** These methods can provide profiles of the top of the aquitard which may represent fractures, bedding planes, or other lineaments. Seismic depths are also used to calibrate microgravity results where no boring data are available. The latter two methods (microgravity and seismic profiling) are also often used to discern the difference between EM or EI conductive anomalies (which could represent either a bedrock low or wet, saturated soils), or between EM or EI resistive anomalies (which could be caused by either dry, competent rock or air-filled voids).

- **Ground Penetrating Radar (GPR):** This method uses high frequency electromagnetic energy to acquire subsurface information. Energy is radiated downward into the ground from a transmitter and is reflected back to a receiving antenna. Reflections of the radar wave occur where there is a change in the dielectric constant between two materials. The reflected signals are recorded and produce a continuous cross-sectional image of shallow subsurface conditions.

These techniques work best when there is little near-surface interference (sometimes called cultural interference). Types of near-surface interference can include, but are not limited to:

- Utility corridors;
- Fill materials;
- Buildings, fences, and
- Reinforced concrete.

If there is significant near surface interference, geophysical investigation results can be misleading and soil borings will produce better results. Also it may be necessary to examine the manmade preferential pathways. Typically at least a few borings are needed to verify the interpretations of geophysical investigations.

<u>Sampling the soil and ground water, to determine if underling units are contaminated.</u>

Once the area where the borings will be placed is determined, a series of probe points are advanced (on a grid pattern) until the top of the aquitard is encountered (collect soil samples in a subset of these "borings"). The depth to the top of the aquitard and the contaminant levels are mapped and, if possible, the "low spot" on the aquitard surface is located. If high levels of soil contamination are identified in the "low spot", there is a high probability that contamination is flowing along the surface of the aquitard. However, prior to investigating the units beneath the aquitard, confirm if water draining from the site is contaminated (i.e. sample the water flowing along the surface of the aquitard).

Soil Sampling: Soil sampling in areas where an aquitard is present should be conducted both in the overlying unit and the top portion of the aquitard. The top of the aquitard is investigated as there is a potential for the aquitard (provided it has been in contact with contamination for a long time) to store contamination and act as a source.

Ground Water Sampling: Once the surface of the aquitard has been mapped, and "low spots" have been identified; several monitoring wells are installed so that the screens intersect the interface between the unconsolidated materials and the aquitard. At least one monitoring well should be installed in each of the identified "low spots". These wells are installed to monitor water flowing along the surface of the aquitard.

REMEDIAL MEASURES

This guide is not intended to be a comprehensive discussion of remedial or closure methods. Not every site will need a specific remedy to remove the risk from contamination remaining in an aquitard. However, if the aquitard is significantly affecting the ground water hydraulics or vapor flow, it can create difficulties for both active and passive closure strategies. A good investigation using the principles noted above should determine if and how aquitards are affecting the contaminant fate and transport. Sometimes, the aquitard can make remediation easier, because contamination has been contained within or above a low permeability unit.

When addressing contamination in areas where an aquitard is a barrier to further contaminant migration, precautions need to be taken not to breach the aquitard. If the aquitard is not deep, remedial measures that are successful in remediation of shallow bedrock can be used. If the aquitard is deep methods used at most unconsolidated sites can be used. If the aquitard is found regionally, the aquitard can be used to demonstrate drinking water supplies will not be affected. However to prove this it should be shown that the well screens for the drinking water wells are screened below the aquitard. Once that is demonstrated, remediation can either be ex-situ or in-situ:

Removal:

If an aquitard is close to the surface, excavation could be an option that may reduce contamination.

In-situ Remediation

There are numerous types of in-situ chemical oxidation (ISCO) systems. Science Services has evaluated various remediation applications using hydrogen peroxide (Fenton's Reagent), magnesium peroxide, magnesium hydroxide, ozone, calcium peroxide, and sodium persulfate; with or without special catalysts, pH adjustment compounds, and iron supplements. All of these are intended to chemically break down contamination. Some of these have oxygen as a theoretical end product, which may stimulate aerobic microbes (those not killed by the peroxides and toxic secondary chemicals).

Chemical oxidation of contaminants involves injecting or emplacing a highly reactive substance to break apart the bonds in a contaminant compound, usually by inserting oxygen. It will physically destroy the molecule. This is notably different from bioremediation, in which microbes gradually strip off elements for use as food, but leave the rest of the molecule intact.

These chemical oxidants should not be confused with agents such as Oxygen Release Compound (ORC)™ sold by Regenesis, which is a magnesium peroxide with phosphate added to form time-release crystals. ORC is used to provide oxygen to stimulate microbial action, rather than for chemical oxidation. For more information on the use of in-situ chemical oxidation, see the Technology Evaluation Group In-Situ Chemical Oxidation Technical Guidance Document, Dated April 6, 2005 (Revised October 27, 2010). For a copy of this document refer to the following link: http://www.in.gov/idem/files/remediation_tech_guidance_in-situ.pdf

Extraction Based Technologies

Given that aquitards are composed mostly of clays, the use of extraction based technologies (like SVE, MPE, pump and treat) may not be effective. Bio-remediation or stability monitoring would be more effective in these situations. Additionally, remediation at the point of exposure, for example placing carbon filtration systems on water supply wells, could be used.

Summary and Conclusions

Staff assembled the information contained in this document from sites in Indiana, the references provided, and staff training and experiences. This document provides a basic outline for investigating aquitards. More in-depth evaluations should be determined on a site by site basis. An understanding of the nature of not only the materials associated with aquitards, but also how ground water interacts with those materials is needed to develop an accurate CSM. When an aquitard is present a successful remedial approach may involve a combination of remediation methods.

References and Further Reading

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